

FINAL REPORT:

**Forest Practices and Their Effects on
Water Resources in the Lake Whatcom Watershed:
A Review of Existing Information**

Prepared for:
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Introduction

This document was prepared for the Department of Natural Resources (DNR) Lake Whatcom Planning Team to help evaluate water quality and quantity issues related to forest practices in the Lake Whatcom watershed. The document describes the current condition of water resources in the watershed, discusses the physical watershed processes that influence water resource characteristics, and evaluates the extent to which forest practices have altered resource conditions. In addition, existing regulations and policies designed to prevent or minimize negative resource impacts associated with forest practices are discussed.

Physical and chemical water quality attributes that are affected by forest management activities will be the focus of the report; biological water quality attributes important to fish habitat are evaluated in a separate document prepared for the Planning Team. In addition to water quality considerations, the influence of forest management on streamflows (i.e., water quantity) will also be reviewed.

Current water resource conditions in the watershed were assessed using local data obtained from a variety of sources including the Washington Department of Natural Resources, Western Washington University, the City of Bellingham, and Whatcom County. The effects of forest management practices on watershed processes and resource conditions were evaluated using information from local reports and regional studies.

Lake Whatcom Watershed and Associated Water Resources

The Lake Whatcom watershed encompasses approximately 36,300 acres with Lake Whatcom comprising nearly 5,000 acres of the total area. Although a large majority of the watershed lies in Whatcom County, the southernmost portion is located in Skagit County. Nearly 70 percent of the watershed area is designated as forest land based on Whatcom County zoning. Elevations range from 310 feet at the lake outlet to approximately 3,300 feet at the south end of the watershed. Slopes are typical of mountainous terrain in western Washington, ranging from nearly flat along the lakeshore to very steep in the headwaters of tributary streams. Soils are generally shallow (<3 feet) and are derived from glacial till, bedrock or colluvial deposits. Average annual precipitation has been estimated at 48 inches (WSPP, 2000), however, this may underrepresent actual precipitation since most of the recording gages are located at lower elevations where less precipitation typically falls.

The primary water resource in the watershed is Lake Whatcom. The lake is 11.9 miles long and averages 0.75 miles wide (WSPP, 2000). It is comprised of three distinct basins; the northernmost basins (1 and 2) are relatively shallow (<100 feet) and contain approximately four percent of the total lake volume. The southern basin (3) is deep (>300 feet) and contains the remaining 96 percent of lake volume. Two sills separate these adjacent basins. The Geneva Sill, with a maximum depth of approximately 10 feet, isolates Basin 1 at its eastern end. The Strawberry Sill has a maximum depth of 46 feet and separates Basins 2 and 3 (WSPP, 2000).

Surface water inputs to Lake Whatcom are provided by more than 50 streams. Of these, three (Smith Creek, Anderson Creek and Austin Creek), provide the greatest inflow to the lake. While Smith and Austin Creeks are natural, unregulated streams, flows in Anderson Creek are controlled by a diversion dam on the Middle Fork Nooksack River. The hydrographs of unregulated streams in the watershed mimic seasonal rainfall patterns, with peak flows occurring during the wet fall and winter months (November through February) and low flows occurring during the drier summer months (July through September). Due to the shallow nature of soils in the watershed, streams are fairly responsive to rain and snowmelt inputs, particularly during fall and winter months when soils are near saturation. Highest flows in Anderson Creek generally occur during summer months when the diversion is operating to maintain lake levels.

Most channels in the watershed are typical of streams draining mountainous terrain, exhibiting high gradients and narrow valleys. Since the last glacial period, mass wasting processes have been the primary agent shaping the character of these streams. Coarse and fine sediment inputs from hillslope landsliding are transported through stream channels and are deposited in the lake, forming alluvial fans along the lake margin. Flows in Whatcom Creek, the only natural surface water outlet for Lake Whatcom, are regulated via a control structure near the lake outlet.

Current Resource Conditions

This section provides an overview of current water resource conditions in the watershed relative to four parameters - sediment, temperature, nutrients, and hydrology. These parameters represent resource conditions most likely to be affected by forest practices activities. This is consistent with the assumptions of Washington's watershed analysis process for assessing the effects of forest practices on public resources (WFPB 1997). The effects of forest practices on large woody debris levels are discussed in this section only in relation to wood's role in sediment storage. The biological/habitat functions associated with woody debris are discussed in a separate document prepared for the Planning Team. Most information presented is based on local reports issued by state and local governments and private consulting firms.

Tributary Streams - Sediment

Background - Sediment arguably has the greatest potential to adversely impact a wide range of resource conditions in the Lake Whatcom watershed. Fine sediment entering streams affects suspended sediment concentrations which may degrade beneficial uses such as fish habitat and drinking water quality. Coarse sediment produces changes in channel morphology that may alter the quality and quantity of fish habitat as well as the thermal regime of tributary streams.

Due to the high gradient and confined nature of streams in the watershed, sediment delivered to channels is efficiently transported to Lake Whatcom. Therefore, little opportunity exists for significant long-term, in-channel sediment storage (Gacek Associates, 1990; WDNR, 1997). Short-term storage is typically associated with woody debris jams and bedrock outcrops in some of the larger tributaries; however, due to current low in-stream wood levels in the fish-bearing portion of the stream network, wood-associated storage is limited (WDNR, 1997). In some cases, sediment that has historically deposited on alluvial fans now reaches the lake more quickly

due to fan modification by dikes (WDNR, 1997). Particle size analysis has shown most sediment delivered to channels is fine-textured; approximately half of the total sediment load consists of sand or smaller sized particles (i.e., <2mm) and 70 percent is smaller than 11.2mm (pebble-sized) (Gacek Associates, 1990). In addition, due to the weak nature of bedrock parent materials in the watershed (sandstone and phyllite), larger sediment particles tend to break down quickly once they reach stream channels (WDNR, 1997). The fine texture of sediments in the watershed combined with channel morphologies that efficiently transport sediment results in naturally high rates of sediment input to Lake Whatcom.

Current Conditions - The current condition of most channels in the Lake Whatcom watershed is largely reflective of a single, large magnitude storm event that occurred in January 1983. During this storm, shallow-rapid landslides and debris torrents delivered sediment to many channels throughout the watershed. Those impacted most severely included Austin, Smith, Olsen, and several smaller, unnamed tributaries in the Blue Canyon area.

The watershed analysis conducted by WDNR (1997) highlights several direct and indirect effects of the 1983 storm on sediment dynamics in tributary channels. In basins where landsliding and debris torrents occurred (e.g., Austin, Smith, and Olsen), sediment delivery resulted in dramatic, short-term increases in suspended sediment concentrations in tributary streams. Scoured streambanks and valley walls served as chronic sources of fine sediment for several years following the 1983 event. Watershed analysis results indicate fine sediment levels are currently low in the fish-bearing portions of Austin and Smith Creeks, primarily due to the high transport and limited storage capacities of these systems (WDNR, 1997). This suggests that most of the fine sediment delivered to these channels in 1983 and subsequent years has been routed to Lake Whatcom rather than being retained in-stream (Gacek Associates, 1990). Unlike Austin and Smith Creeks, lower Olsen Creek was found to have high levels of fine sediment (WDNR, 1997). It was hypothesized that relative to Austin and Smith, Olsen Creek had a higher frequency of unvegetated, stream-adjacent landslide scars that served as chronic sediment sources; in addition, comparing the lower reaches of Austin and Smith Creek with Olsen Creek shows Olsen contains a low-gradient depositional reach where fine sediment is more likely to accumulate. Fine sediment accumulations in lower Olsen Creek were randomly distributed, owing to a lack of in-stream roughness elements that normally serve to sort sediments. High fine sediment levels were also documented in the fish-bearing portions of Carpenter, Fir, and Anderson Creeks and were attributed to high upstream sediment supplies and a low number of in-stream roughness elements (WDNR, 1997).

In addition to increases in fine sediment, large volumes of coarse sediment were delivered to streams as a result of landsliding associated with the January 1983 storm. Much of this material was deposited in low gradient reaches and on alluvial fans and did not reach Lake Whatcom. Many of these deposits still persist, continuing to be eroded during high streamflows. Much of this “reworked” sediment is transported to tributary mouths and alluvial fans on an annual basis. As a result, the lower reaches of some channels have experienced significant bed aggradation (filling). This has been most notable in Brannian Creek where sediment deposition has limited

kokanee access to the Brannian Creek hatchery during low flows (WDNR, 1997). Aggradation has transformed some perennial stream reaches into seasonally flowing streams where no surface flow occurs during late summer and/or early fall. This process has led to the perception that “logging dries up streams”, a conclusion that is not supported by the scientific literature as will be discussed later in this report. In cases where sediment inputs return to near-background levels, sediment export from aggraded reaches should allow perennial flow to return to many of these areas.

In many channels, debris torrents have also reduced woody debris loads. Where they occurred, debris torrents scoured streambeds and banks, effectively removing all functional wood from the scoured reach. Debris torrents scoured valley walls to bedrock along tightly confined reaches, removing riparian vegetation and reducing future wood recruitment potential. Routine removal of wood from streams also occurs in some areas (WDNR, 1997). Reductions in wood levels directly affect sediment dynamics in tributary channels. In many cases, wood is the primary roughness element that sorts and retains (i.e., stores) sediment in streams. In addition, wood helps dissipate stream energy, reducing sediment transport capacity. In the absence of wood, channels are much more efficient at routing sediment to downstream reaches and Lake Whatcom. As riparian vegetation recovers, recruitment of large, stable wood pieces is likely to reduce sediment transport capacity and increase the retention of coarse and fine sediment. Local sediment accumulations may also provide important spawning habitat for resident trout and kokanee (WDNR, 1997). The assessment of riparian vegetation condition by WDNR (1997) indicates that only eight percent of the fish-bearing stream network currently has a “high” potential for recruitment of functional woody debris. Therefore, wood levels are not expected to recover for several decades; in areas where riparian areas have been converted to non-forest land uses, wood levels are likely to remain at low levels.

Tributary Streams - Temperature

Background - Temperature is a principal regulator of biologic activity in aquatic environments. Metabolic rates of various organisms are heavily influenced by water temperature and these rates proceed most efficiently within a limited range of temperatures. Therefore, temperatures outside this range may negatively impact aquatic life. High water temperatures rarely result in the direct mortality of fish and other organisms; more commonly, increased temperatures result in accelerated rates of metabolic activity, which increases energy demands and predisposes organisms to disease (Brown, 1989).

Current Condition - Temperature data for several lake tributaries was collected by the Institute for Watershed Studies (IWS) at Western Washington University during 1990 and 1999. In addition to this quantitative information, DNR conducted an indirect assessment of temperature by evaluating riparian canopy cover throughout the watershed as part of the Lake Whatcom watershed analysis (WDNR, 1997).

The IWS monitoring included four streams whose watersheds were predominately forested (Austin, Smith, Blue Canyon, and Wildwood; Anderson Creek was also included, but due to the

influence of the Middle Fork diversion, it was not considered in this assessment). Daily monitoring from 1990 indicated maximum recorded temperatures in all four streams exceeded the Class AA 16.3 degree C water quality standard (Matthews et al., 2000). Grab samples taken in July 1999 from these same streams showed temperatures at that time were several degrees below the temperature threshold (Matthews et al., 2000), however, peak temperatures typically occur later in the summer (i.e., August or September). Also, grab sample data often does not capture annual temperature maxima due to large within-day and between-day fluctuations in water temperatures.

The high recorded temperatures described above are somewhat in conflict with the DNR assessment of riparian canopy cover. In that analysis, 75 percent of the assessed stream length in the watershed was determined to have sufficient canopy cover necessary to meet the Class AA temperature standard (WDNR, 1997). Several reasons could explain the discrepancy between the 1990 IWS temperature data and the DNR riparian canopy cover assessment. First, the DNR assessment relied on 1995 aerial photography to estimate canopy cover. It is possible that canopy cover in forested riparian areas increased during the five year period between the 1990 temperature monitoring and the 1995 canopy assessment. This would suggest that while temperature standards were exceeded in 1990, the increased canopy cover documented in 1995 resulted in temperature recovery, or lower maximum summer temperatures. However, this is unlikely since significant increases in canopy cover would not be expected over a five-year period. Second, since the minimum canopy cover requirements were developed using a data set obtained from sites distributed throughout western Washington, it is likely that those requirements are not applicable in all watersheds. Therefore, it is possible that the minimum requirements stipulated in the watershed analysis are not representative of conditions in the Lake Whatcom watershed. This is a more plausible explanation. Finally, climate data shows the summer of 1990 was unusually warm; average monthly maximum air temperatures in Bellingham for July, August, and September were 3.8, 3.5, and 1.8 degrees C warmer than the long-term average. It is very likely these warmer air temperatures were the primary factor contributing to the high temperatures recorded in 1990. Since the 1990 data may be somewhat anomalous, additional monitoring would help determine if stream temperatures exceed the water quality standard under average summer weather conditions.

Tributary Streams - Nutrients

Background - Generally, nutrient levels in streams draining forest lands are very low. From a biological standpoint, waters with low nutrient levels are not very productive. Production in these systems is largely controlled by inputs of organic nutrients from litter fall or inorganic sources (i.e., sediment) outside the stream. Increased nutrient loading may accelerate primary productivity; however, in forest streams, nutrients rarely degrade beneficial uses (Brown, 1989)

Current Condition - Nutrient levels in tributary streams have been reported by both the IWS and DNR. The IWS monitored nitrogen and phosphorus concentrations in seven tributary streams during 1990 and 1999 (Matthews et al., 2000). The DNR, as part of an aerial fertilization

project, monitored nitrogen concentrations at nine stream sites during the winter of 1981-82 (Ryan, 1984).

The IWS data indicate that combined nitrite-nitrate ($\text{NO}_2 + \text{NO}_3$) concentrations for forest streams were within expected ranges, with peak concentrations occurring during the wetter winter months when these compounds are leached from the soil (Matthews et al., 2000). Wildwood Creek has been noted as having higher nitrate (NO_3) concentrations relative to other forest streams in the watershed. One possible explanation for the elevated levels of nitrate in Wildwood Creek is the abundance of red alder trees (*Alnus rubra*) in the watershed (WSPP, 2000). Phosphorus concentrations reported by the IWS were very low for all forest streams (Matthews et al., 2000), however, total phosphorus concentrations in several tributaries increased significantly during a November 1990 storm event. These increases were short-lived and attributed to upstream mass wasting events that delivered sediment to headwater stream reaches (WSPP, 2000). Mean annual total phosphorus concentrations reported by the IWS are consistent with research findings from other forested watersheds in the Pacific Northwest (Salminen and Beschta, 1991; Dissmeyer, 2000).

Nitrite (NO_2) and nitrate (NO_3) concentrations were measured by the DNR during the winter of 1981-82 in Beaver, Austin, Wildwood, Fir, and several unnamed streams along Lake Whatcom Boulevard. Data indicated maximum concentrations of both nitrite and nitrate remained low throughout the five month monitoring period while maximum ammonia (NH_4) concentrations increased significantly four to five days following a forest fertilization operation (Ryan, 1984). Peak ammonia concentrations were preceded by two days of heavy rainfall which was thought to contribute to the elevated levels of ammonia. Total nitrogen concentrations also reached significant levels, typically in association with periods of heavy rainfall when organic matter was likely to have entered stream channels. However, two of the extreme peaks occurred during fertilizer application when precipitation was low. The author concluded that these two extremes were probably the result of direct application of fertilizer to small tributaries upstream of the monitoring stations. Generally, the fertilization project was thought to have had little effect on both short and long-term nutrient levels in watershed streams (Ryan, 1984).

Lake Whatcom - Nutrients

A comprehensive discussion of the current condition of Lake Whatcom relative to nutrients is beyond the scope of this assessment given the complexity of the issue. However, some generally accepted principles regarding lake phosphorus levels are presented based on the recently published Water Source Protection Plan for the Lake Whatcom Watershed (WSPP, 2000). The discussion focuses on phosphorus since most information indicates phosphorus limits primary productivity in Lake Whatcom (Entranco, 1999).

Both soluble phosphate and total phosphorous concentrations are usually very low throughout the lake. A common exception occurs when phosphorus is released from lake bed sediments under low oxygen conditions in Basin 1. Under these conditions, phosphorus may move to within 30 feet of the lake surface, where it becomes more accessible to phytoplankton, thereby

increasing overall productivity in the basin. These elevated levels do not persist for long periods due to intense competition for phosphorus by algae. While these same conditions may occur in Basin 2, they do not occur in Basin 3 where colder water temperatures and lower nutrient concentrations allow for the maintenance of relatively high hypolimnetic oxygen concentrations (WSPP, 2000).

Tributary streams contribute both soluble phosphate and total (bound) phosphorus to Lake Whatcom. Soluble phosphate concentrations in tributary streams are stable relative to total phosphorus concentrations, which vary with basin sediment yield (Dissmeyer, 2000). Thus, land use activities in the watershed which tend to accelerate erosion and sediment delivery to streams will increase total phosphorus inputs to Lake Whatcom.

Tributary Streams – Hydrology

Background - The hydrologic regime of streams in the Lake Whatcom watershed affects both the quality and quantity of fish habitat. During fall and winter months, peak streamflows often mobilize bed sediments, potentially flushing kokanee eggs from redds. During summer and early fall, low streamflows affect the amount of habitat available for use by resident trout. Annual water yield (total discharge) from tributary streams also affects lake water levels, however, the Middle Fork Nooksack diversion currently exerts a greater influence on lake levels than all other tributary streams combined.

Current Condition - Limited quantitative information is available regarding the current hydrologic regime of Lake Whatcom tributary streams. Streamflow has been monitored at a number of locations throughout the watershed at irregular intervals. From the 1940's through the 1970s, the United States Geological Survey (USGS) periodically maintained gaging stations on Anderson Creek, Austin Creek, Smith Creek, and Olsen Creek (Williams et al., 1985). The IWS has also monitored streamflow on several lake tributaries. From May 1990 through April 1991, the IWS maintained gages on ten streams including Anderson, Austin, Smith, Silver Beach, Wildwood, and Blue Canyon Creeks (WSPP, 2000). More recently, the IWS established two gages, one on Austin Creek and one on Smith Creek (Matthews et al., 2000). While little information has been obtained from the Smith Creek gage due to storm damage and vandalism, the Austin Creek gage produced streamflow data for the 1999 water year. Both gages continue to operate and are expected to yield data for both the 2000 and 2001 water years.

In most cases, insufficient data currently exist to establish a reliable flood frequency curve for streams in the watershed. Generally, at least 10 years of data are needed to establish such a curve and the longest period of annual peak flow record for unregulated streams in the watershed appears to be eight years (Austin and Olsen). Continued monitoring by the IWS may provide enough data to create useful flood frequency curves for several lake tributaries in the future. This information, combined with longer-term streamflow monitoring is likely to yield valuable insight into the hydrologic regime of small, forested watersheds in western Washington.

While peak flows are typically the primary hydrologic issue on forest lands, summer low flows are likely to be of some interest in Lake Whatcom. Since water diversions from the Middle Fork Nooksack could be reduced in the future, interest in maintaining natural inflows from tributary streams may increase. Here again, quantitative information regarding summer low flows is limited. Given the interrupted nature and short period of record, little is known about the low flow regimes of tributary streams. Recent reports suggest Austin and Smith Creeks are the only unregulated perennial streams in the basin (WSPP, 2000), however, anecdotal information indicates perennial flow may exist in other tributary streams. Some lower stream reaches have experienced aggradation (i.e., filling) over the past few decades due to high sediment inputs associated with accelerated rates of mass wasting (WDNR, 1997). Aggradation often results in the transformation of perennial streams to intermittent (i.e., seasonal) streams since water formerly at the surface is relegated to subsurface flow. In cases where sediment supplies return to near-background levels, sediment in aggraded reaches will be routed downstream during high flows, in which case perennial flow may be restored. However, inflows to the lake from tributary watersheds have a significant effect on lake levels, irrespective of the nature of the flow (i.e., surface vs. subsurface).

Forest Practices Effects on Resource Conditions

This section presents information regarding the cause-and-effect linkages between forest practices and the water quality/quantity parameters discussed above. Where available, local reports were consulted to describe these linkages; in the absence of local information, results from regional studies were utilized. Also included is an overview of existing regulations and policies designed to prevent or minimize negative resource impacts associated with forestry operations.

Sediment

Sediment inputs to Lake Whatcom and its tributaries have increased over background levels as a result of past forest practices. The extent of the increase was determined by examining information contained in the Lake Whatcom watershed analysis (WDNR, 1997) and the Smith Creek Timber Harvest Plan (Gacek Associates, 1990). Background (i.e., natural) and road-related sediment yields were derived from the watershed analysis surface erosion module (WDNR, 1997) while estimates of mass wasting related sediment inputs were based on data from the watershed analysis mass wasting module (WDNR, 1997) and the Smith Creek Timber Harvest Plan (Gacek Associates, 1990).

Background Sediment Yield - The background sediment yield for the Lake Whatcom watershed was estimated at 6,235 tons/year (WDNR, 1997). This figure does not include artificial (i.e., human-caused) inputs from land use activities or the Middle Fork Nooksack diversion. Expressed on a unit area basis, the background yield for the watershed is 49 tons/km²/year. This figure is consistent with a study by Benda and Dunne (1987) where background sediment yield was estimated at 43 tons/km²/year, but lower than studies of other forest watersheds in the Pacific Northwest where yields have ranged from 75 to 80 tons/km²/year (Swanson et al., 1982).

Differences in background yields between watersheds are attributable to variations in climate, geology, and topography.

Forestry-Related Increases in Sediment Yield - Forest practices-related sediment delivery was estimated by separating inputs into categories based on erosional process (surface erosion and mass wasting) and sediment particle size (fine and coarse). While both erosional processes generate fine sediment, it was assumed that all coarse sediment inputs were associated with mass wasting.

Surface Erosion - According to the Lake Whatcom watershed analysis (WDNR, 1997), virtually all forestry-related surface erosion was associated with forest roads. Field review of 33 areas that had been clearcut harvested between 1990 and 1995 showed little evidence of increased hillslope surface erosion due to timber harvesting (i.e., felling, bucking, and log yarding). The primary conclusion from these field reviews was that standard forest practices regulations, when followed, effectively minimized hillslope surface erosion and fine sediment delivery to waters in the watershed. Roads in the watershed, however, were found to generate significant quantities of fine sediment. Based on watershed analysis data (WDNR, 1997), fine sediment inputs associated with road surface erosion totaled 1,227 tons/year for all roads in the watershed. Of this total, 60 percent, or 732 tons/year, was contributed by forest roads.

Mass Wasting - Sediment inputs associated with forestry-related mass wasting were more difficult to estimate. As part of the Lake Whatcom watershed analysis (WDNR, 1997), a comprehensive landslide inventory was compiled using aerial photos spanning the period 1943-1995. Each landslide was classified based on time of occurrence, associated land use, whether sediment was delivered to water, and mass wasting process (shallow-rapid versus deep-seated).

To calculate the forest practices sediment contribution from mass wasting, the landslide inventory was used to determine the number of shallow-rapid landslides with a forestry-related triggering mechanism that also delivered sediment to waters. It was assumed that the effective period of record extended beyond the photo record since 1943 aerial photos could be used to detect landslides that occurred at least 10 years prior, and known landslide occurrence since 1995 has been documented through observational/anecdotal evidence. Therefore, the effective period of record was assumed to be 67 years (1933-2000). Individual landslide volume was estimated using data from Gacek Associates (1990), which reported the average volume of seven landslides in the Smith Creek sub-basin of Lake Whatcom based on information from Buchanan (1988). Only landslides from watershed analysis mass wasting map unit 4 (Chuckanut formation) were used to estimate sediment inputs. Although this ignores sediment inputs associated with mass wasting in the Darrington phyllite formation, map unit 4 includes over 90 percent of all documented landslides and is by far the largest high hazard mass wasting unit in the watershed at 2,888 acres (WDNR, 1997). In addition, Buchanan's estimate of landslide volume is only applicable to map unit 4 since all seven landslides were located in the Chuckanut formation. Deep-seated landslides were not included in the total since 20 of the 21 documented slides of this

type were associated with mature (>50 years) forest conditions (i.e., no forestry-related trigger) and would therefore be part of the background sediment yield.

While the landslide inventory provides a sound basis for estimating landslide frequency in the watershed, the small number of landslides (7) used to derive the volume estimate admittedly represents a weakness in the analysis. A more accurate estimate of mass wasting-associated sediment inputs could be achieved by measuring a larger number of landslide volumes. However, estimates of mass wasting inputs are thought to be fairly reasonable due to the high quality of the baseline inventory.

Following the methods outlined above, forestry-related sediment inputs associated with mass wasting totaled 18,956 tons/year, or roughly three times the background sediment yield of the watershed. This figure is slightly higher than an estimated increase of 2.6 times the background yield calculated by Gacek Associates (1990) for harvesting and road construction in the Smith Creek sub-basin. However, both values likely overestimate expected future inputs from forestry for two reasons. First, of the 294 landslides documented from 1933-2000, nearly half (134) occurred as a result of the January 1983 storm event. The recurrence interval of this storm has been estimated at between 80 and 100+ years (Orme, 1990). Including a storm of this magnitude in the calculation of sediment inputs over a period of record shorter than the storm recurrence interval artificially inflates the average sediment yield. Lengthening the period of record to account for the magnitude of the January 1983 event would likely result in a more realistic estimate of sediment yield. If a 90 year period of record is used in the calculation, the average forestry-related sediment yield drops to 14,112 tons/year, or 2.3 times the background rate.

While increasing the period of record addresses the magnitude of the 1983 event, it does not address the “legacy effect” of historic forest practices, which is the second factor contributing to the overestimate of future forestry-related sediment inputs. Much of the sediment delivery that resulted from the January 1983 storm was associated with logging that occurred well before the existence of forest practices regulations. Furthermore, the large majority of forestry-related sediment inputs reflected in the aforementioned estimates was associated with this one storm event (WDNR, 1997). Much of the timber harvesting and road construction that set the stage for the catastrophic damage that occurred in 1983 occurred from the 1940's through the 1960's before the cause-and-effect linkages between logging and landsliding were understood or acknowledged. Since that time, understanding of those linkages has vastly improved, resulting in regulations that focus on the identification of landslide-prone slopes and impose higher road construction standards and limitations on timber harvesting in those areas.

Yield Increases - Based on the above analysis, forest practices have increased sediment inputs in the Lake Whatcom watershed by 14,844 tons/year, or 2.4 times the background yield. Nearly all this increase (95 percent) has been associated with mass wasting. Approximately 43 percent of the forestry-related contributions was attributed to landsliding that occurred during the January 1983 storm. During this event, orphaned forest roads were the primary triggering mechanism behind most of the landslides (WDNR, 1997).

Except for fine sediment contributions from non-forest roads, the above analysis ignores sediment inputs from all other land uses in the watershed. Little information was available to construct a complete sediment budget for the watershed, therefore the proportion of the total watershed sediment load contributed by forest practices is unknown. While development and agriculture undoubtedly accelerate erosional processes in the watershed, a lack of local data makes quantifying sediment inputs from these land uses beyond the scope of this analysis. One non-forestry sediment source that has been quantified is the Middle Fork Nooksack diversion. Based on studies of sediment deposition in Mirror Lake, inputs from the diversion have been estimated at between 367 and 447 tons/year (Carpenter et al., 1992). This represents a relatively small (7 to 8 percent) increase over background yields.

Three significant regulatory and policy changes that have occurred in the past five years will facilitate reductions in erosion and sedimentation associated with logging and road construction. First, management prescriptions developed as part of the Lake Whatcom watershed analysis now guide forest practices on all lands within the watershed. A number of these prescriptions are focused specifically on preventing accelerated erosion by requiring improved road maintenance practices, imposing higher standards for newly constructed roads, and prohibiting timber harvesting on landslide-prone slopes. These prescriptions were largely based on lessons learned from studying triggering mechanisms for landslides that occurred during the January 1983 storm event. All forest practices in the watershed, irrespective of ownership, must meet or exceed the standards established under these management prescriptions. The second significant regulatory change was the adoption of new standard forest practices rules based on the Forests and Fish Report (WDNR, 2000). These new rules require large forest landowners to develop road maintenance and abandonment plans for all forest roads by the year 2005. Implementation of the plans will be phased in over time, with all roads meeting the new standards by 2020. While these plans may result in some reductions in mass wasting-associated sediment delivery in the watershed, the biggest benefits are likely to be associated with reductions in fine sediment from road surface erosion. Finally, forest practices on DNR-managed lands in the watershed are also subject to requirements of the DNR-Habitat Conservation Plan (HCP), which establishes broader, performance-based standards for minimizing erosion and sedimentation.

Temperature

Forest practices have the potential to affect the thermal regime of streams by reducing the amount of riparian canopy cover, or shade (Beschta et al., 1987; Brown, 1989). Shade can be reduced directly through the loss of riparian trees (i.e., harvest) or indirectly through changes in channel morphology (i.e., channel widening). Reduced shade levels in some Lake Whatcom tributaries have been attributed to historic riparian timber harvest and debris torrent scour associated with the January 1983 storm (WDNR, 1997). Shade levels in larger tributary streams (e.g., Austin, Smith, and Olsen) are still recovering from these effects and are unlikely to return to pre-management conditions in the near future.

Current forest practices rules require the retention of all shade-providing trees within 75 feet of fish-bearing streams (WFPB, 2000). Additionally, all trees must be retained within 50 feet of perennial non-fish bearing streams along half their length (WFPB, 2000). DNR-managed lands within the watershed are subject to requirements in the Department's HCP, which provide higher levels of riparian protection relative to current forest practices rules. The HCP-prescribed buffers currently require the retention of all trees within one site-potential tree height (generally 120 to 160 feet) of fish-bearing streams and 100 feet of perennial non-fish bearing streams (WDNR, 1997b). Regional studies show buffer strips with widths of 100 feet or more generally provide the same level of shading as that of an old-growth forest (Beschta et al., 1987). Therefore, future timber harvesting on DNR-managed lands is expected to result in little, if any, reduction in potential shade while harvesting on private lands may reduce shade levels along some waters, particularly small, non-fish bearing streams. As shade levels recover from past timber harvest and debris torrent effects, thermal regimes of forested tributary streams should return to near background levels.

Nutrients

The effects of forest practices on nutrient levels have been described by Dissmeyer (2000). Research studies have demonstrated that both timber harvesting and forest fertilization can increase nitrate concentrations in soil water and streams. However, increases tend to be short-lived due to rapid vegetation regrowth and associated nutrient uptake. In addition, nitrate increases typically do not approach levels that degrade water quality (Dissmeyer, 2000). Results from forest fertilization studies indicate concentrations of ammonium are not affected by fertilization (NCASI 1999 in Dissmeyer 2000). It should be noted that these conclusions are based on the assumption that no fertilizer is applied directly to streams; in cases where fertilizer enters streams, increased concentrations of both nitrate and ammonium may result (Dissmeyer 2000; Ryan, 1984). Therefore, operations that avoid the direct application of fertilizer to streams should have little effect on nitrate and/or ammonium concentrations.

Soluble phosphorus concentrations are essentially unaffected by forest practices activities (Dissmeyer, 2000). Soluble phosphorus loads, however, may be increased as a result of increases in water yield associated with timber harvesting (Salminen and Beschta, 1991). Because phosphorus loads are the product of concentrations and annual streamflow, an increase in flow without any change in concentration will increase the load. Most water yield increases due to harvesting occur during the late fall and winter; summer increases are usually small and persist only for a few years. As a result, any additional export of phosphorus associated with increased water yields generally occurs outside the summer season when primary productivity may be affected (Salminen and Beschta, 1991). Therefore, forest practices in the Lake Whatcom watershed are unlikely to have a measurable effect on soluble phosphorus concentrations.

According to Dissmeyer (2000), total phosphorus concentrations are closely linked to sediment concentrations, thus practices that increase sediment production have similar effects on total

phosphorus. However, in a review of five studies in the Pacific Northwest that investigated the effects of forest practices on streamwater phosphorus levels in more than 15 watersheds, Salminen and Beschta (1991) found that none of the studies reported increases in total phosphorus concentrations or loads. The treatments in these watersheds ranged from 3 percent of the watershed area clearcut to 40 percent clearcut with road construction and slash burning. The lack of response in these studies may be due to low sediment delivery and/or low phosphorus contents in parent materials. In the Lake Whatcom watershed, total phosphorus concentrations have been shown to increase in response to high suspended sediment concentrations that occur during storm events (Walker et al., 1992). Hence, forest practices that minimize erosion and sedimentation will limit total phosphorus loading in the watershed.

Phosphorus adsorbed onto sediments is unavailable for use by organisms. However, in lentic systems, this “bound” form of phosphorus can be released from bed sediments into the water column under anaerobic conditions (Wetzel, 1983, WSPP, 2000). In Lake Whatcom, this process is thought to occur in Basin 1 but not in Basins 2 or 3 due to the relatively high hypolimnetic oxygen levels in the latter two basins (WSPP, 2000; Entranco, 1999). It has been proposed that sediment originating from forest lands serves as a phosphorus source that could contribute to the release of phosphorus into Lake Whatcom. Phosphorus adsorbed onto sediment particles is transported to the lake during high flows where it settles to the lake bottom. Under anaerobic conditions, the bound phosphorus is released into the water column where, in its soluble form, it is available for use by organisms.

Given the current knowledge of sediment and phosphorus dynamics in Lake Whatcom, the likelihood for increased sediment production associated with forest practices to exacerbate phosphorus release in Lake Whatcom is relatively low. Several reasons are provided in support of this conclusion. First, few forest streams are tributary to Basin 1 where the release of phosphorus from sediments is thought to occur; most forest streams capable of delivering significant volumes of sediment to the lake drain into Basin 3. Therefore, the potential for forest practices to contribute sediment directly to Basin 1 is low. Secondly, while suspended sediment originating from Basin 3 may be transported through the lake water column to Basin 1, this is likely to occur only during large magnitude storm events when suspended sediment concentrations in the lake are relatively high. This occurred in 1983 and again in 1990 when hillslope landsliding delivered sediment to tributary streams. The volume of sediment deposited in the lake as a result of these events is unknown; while most of the coarse sediment settled out on alluvial fans and in low-gradient stream reaches, a significant portion of the finer particles reached the lake and were transported to Basin 1. Third, increased sediment production does not necessarily increase the total amount of phosphorus available for release. Studies have shown that when anoxic conditions occur in lake bed sediments and overlying water, the release of phosphorus extends several centimeters into the sediments (Hynes and Greib, 1970 in Wetzel, 1983). This suggests that the depth from which phosphorus can be released from sediments is limited. While sediment reaching the lake bottom represents a new source of phosphorus, it renders deeper sources unavailable. So, although sediment deposited in the lake may serve as an alternate *source* of phosphorus, it does not necessarily increase the *amount* of phosphorus

available for release. Finally, the total amount of phosphorus available in lake bed sediments is extremely large; under current conditions, the phosphorus supply in those sediments greatly exceeds demand for its release. Therefore, even if available supply were to increase, it is unlikely this would accelerate phosphorus release. For these reasons, it is unlikely sediment deposition in the lake will exacerbate the release of phosphorus that has been documented in Basin 1.

Hydrology

Numerous studies throughout the Pacific Northwest have investigated the effects of forest practices on hydrology. Changes in water yield (total annual streamflow), peak flows, and low flows have all been evaluated across a range of spatial and temporal scales. Results of these studies have shown increases, decreases and no changes in these hydrologic parameters depending on the specific location, treatments and duration of study. However, some generally accepted principles have developed from research conducted over the past half century.

Adams and Ringer (1994) provide an excellent summary of nearly all the hydrologic studies related to timber harvesting and road construction in the Northwest. The following overview is based largely on that document except where noted:

Water Yield and Low Flows - Water yield, or total annual streamflow, has generally been shown to increase following timber harvest. The effect is most pronounced when a large portion (i.e., 15 to 20 percent or more) of a watershed is logged. In most cases, studies cite a reduction in evapotranspiration due to tree removal as the primary factor responsible for increased water yields. Following harvest, water that is usually taken up through tree root systems and transpired into the atmosphere remains in the soil, adding to streamflow. Streamflow increases typically decline over time, eventually disappearing once transpiration in the regenerating forest stand approaches that of the original stand. This is generally thought to occur within 20 to 30 years following harvest in western Washington. Since only a small portion of a watershed is typically in an immature condition at any one time, water yield increases due to timber harvest are generally small. Therefore, the effects of timber harvest on increased water yields are usually not a resource concern.

Reports of decreased water yields following timber harvest are rare. One study in the Bull Run watershed near Portland, Oregon showed decreased water yield and low flows following logging in an area where fog drip contributed a significant portion of net precipitation. These decreases disappeared within a few years after harvest as vegetation regrowth apparently restored the fog interception function. In a separate Oregon study, initial increases in summer low flows were followed by decreased low flows. Researchers attributed the decreases to red alder (*Alnus rubra*) regrowth in the riparian zone which was thought to utilize more water than the former conifer-dominated stand (note: this study was conducted during the 1960's when no buffer retention was required along streams). Based on the results of these two studies, timber harvest in the Lake Whatcom watershed is not expected to decrease water yields since: a) fog drip is not a significant contributor to net precipitation in the watershed, b) the geomorphic character of

streams in the watershed is not likely to promote the regrowth of hardwoods in the riparian zone, and c) current forest practices rules do not permit clearcut harvesting in the riparian zone, which would be a prerequisite for hardwood regeneration.

Peak Flows - Research studies investigating the effects of forest practices on peak flows have reported mixed results. While some studies have shown no changes or decreases in peak flows following timber harvest and/or road construction, others have reported increased peak flows. Most documented increases in peak flows have occurred in small watersheds where a significant portion of the area was harvested and/or roaded; in most cases, peak flow increases were associated with low magnitude/high frequency events (e.g., Rothacher, 1973; Harr et al., 1975; Harr et al., 1979; Ziemer, 1981; Hetherington, 1982; Harr, 1986; all reported in Adams and Ringer, 1994). Increased peak flows were most often attributed to two processes: first, reduced evapotranspiration following logging resulted in higher soil moisture levels during late summer/early fall. Early fall rain events that normally recharge soils in forested areas increased subsurface runoff from harvested areas, thus increasing streamflows. The second process by which timber harvest can increase peak flows is through its effect on snow interception and melt in the rain-on-snow zone (generally between 1,600 and 2,600 feet in western Washington). Following harvest in the rain-on-snow zone, higher snow accumulation and melt rates have been documented in clearcut areas relative to adjacent forest stands (Harr and Coffin, 1992), resulting in increase subsurface runoff from harvested areas. Increased peak flows in areas where rain-on-snow is an important hydrologic process have been attributed to these harvest-related effects.

A primary assumption in Washington's current watershed analysis methods is that the greatest potential for significant, long-term cumulative hydrologic effects associated with forest practices is associated with timber harvesting and its influence on rain-on-snow generated peak flows. The effects of logging on rain-on-snow processes in the Lake Whatcom watershed was evaluated as part of the Lake Whatcom watershed analysis (WDNR, 1997). In addition, Walker (1994) conducted a similar assessment using an earlier version of the watershed analysis methodology (WFPB, 1992). The results of both assessments indicate timber harvest has the potential to increase peak flows in tributary streams as a result of rain-on-snow. The Lake Whatcom watershed analysis (WDNR, 1997) estimated 2-year peak flows would be increased from 14 to 21 percent in sub-basins with completely immature (i.e., clearcut) forest conditions. Projected increases from Walker (1994) are slightly higher, ranging from 21 to 26 percent. Sub-basins with the largest projected increases generally have a higher proportion of area within the rain-on-snow zone. According to the Lake Whatcom watershed analysis, the Smith and Olsen Creek sub-basins were most sensitive to rain-on-snow effects; projected increases in the 2-year peak flow were 21 percent for both sub-basins. Increases on this order are typically large enough to change the magnitude of a 2-year flow to that of a 5-year flow.

The Lake Whatcom watershed analysis led to the adoption of special management prescriptions for the Smith and Olsen sub-basins that limit the level of clearcut timber harvest that can occur in those areas. Under these prescriptions, no more than 46 percent of the Olsen sub-basin and 65 percent of the Smith sub-basin can be in an immature forest condition (<40 years) at any one

time. These limits are intended to prevent significant peak flow increases and associated resource impacts.

Summary and Conclusions

Historic forest practices in the watershed have contributed significant amounts of sediment to tributary streams and Lake Whatcom. The largest sediment inputs were associated with mass wasting that occurred during the January 1983 storm event. Landslides triggered by the storm delivered large quantities of coarse and fine sediment; debris torrents destabilized stream beds and banks, resulting in elevated levels of sediment input for several years following the event. In some systems (Smith and Austin), little of this sediment remains due to the high transport capacity of stream channels; in others (Olsen and Brannian), in-stream deposits from 1983 continue to supply sediment to lower stream reaches, resulting in aggraded channel conditions. Increases in sediment delivery attributable to historic forest practices have been estimated at 138 percent.

Temperatures exceeding the state water quality standard have been documented in several lake tributaries. Past forest practices have likely contributed to increased temperatures as a result of riparian shade removal due to riparian timber harvest and debris torrent scour and associated channel widening.

Monitoring of forest streams in the watershed indicate nutrient levels (nitrogen and phosphorus) are very low. Regional studies indicate timber harvesting may increase nitrogen levels, although increases tend to be short-lived and rarely reach levels that pose a threat to beneficial uses. Soluble phosphorus levels are typically unaffected by forest practices, however, total phosphorus levels are correlated with suspended sediment yields. The likelihood for phosphorus attached to sediment particles to affect soluble phosphorus levels in Lake Whatcom is low since accelerated sediment delivery is unlikely to affect the total supply of phosphorus available for release from lake bed sediments. Nevertheless, forest practices that minimize sediment delivery to watershed streams will also limit total phosphorus loading in Lake Whatcom.

Information concerning the hydrologic regime of streams in the Lake Whatcom watershed is currently limited. Regional studies suggest timber harvest may increase water yield and peak flows. While increased water yields may result from timber harvest, significant increases are unlikely since only small portion of any one watershed is typically harvested at a given time. Increased water yields, however, particularly summer yields, may be beneficial since the future of diverted flows from the Middle Fork Nooksack River is uncertain. Modeling of rain-on-snow processes indicate high levels of timber harvest may increase peak flows beyond acceptable levels in the Olsen and Smith sub-basins. Watershed analysis prescriptions were developed which limit the level of clearcut timber harvest.

Current water resource conditions in forested areas of the Lake Whatcom watershed reflect a legacy of poor logging and road construction practices that began near the turn of the century and continued into the 1980's. Watersheds throughout the Pacific Northwest have experienced many

of the same impacts and as a result, resource conditions in those areas are similarly degraded. Research into the effects of forest practices on water quality did not begin in earnest until the 1960's. As the results of this research demonstrated the cause-and-effect link between logging and water quality degradation, several states responded by enacting their first forest practices regulations (e.g., 1974 Washington Forest Practices Act). However, many of these early laws focused only on water quality protection, resulting in minimal gains in overall resource conditions. Research that continued into the 1980's was more broadly focused, evaluating the effects of forestry at a watershed scale. The results of these studies improved our understanding of watershed processes and set the stage for considering potential cumulative effects associated with forest practices. By the early 1990's, more effective regulatory mechanisms were in place to further reduce logging-related impacts.

Within the past five years, three separate regulatory mechanisms have been put in place to protect public resources in the Lake Whatcom watershed. The first, DNR's Habitat Conservation Plan, includes conservation strategies to protect fish, wildlife, and water quality resources on Department-managed lands (WDNR, 1997). Second, management prescriptions generated from the Lake Whatcom Watershed Analysis (WDNR, 1997) apply to all forestlands in the watershed and are focused on reducing forestry-related impacts associated with sediment and hydrologic change. Finally, new forest practices rules (WFPB, 2000) have increased protection of fish habitat and water quality by restricting operations in riparian areas and requiring better forest road maintenance and abandonment practices. The effectiveness of these various regulatory mechanisms will be evaluated through both the proprietary and regulatory Adaptive Management programs in the coming years. Results of these monitoring efforts will provide valuable information to help scientists, managers, and policy-makers develop appropriate management strategies to protect public resources into the future.

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